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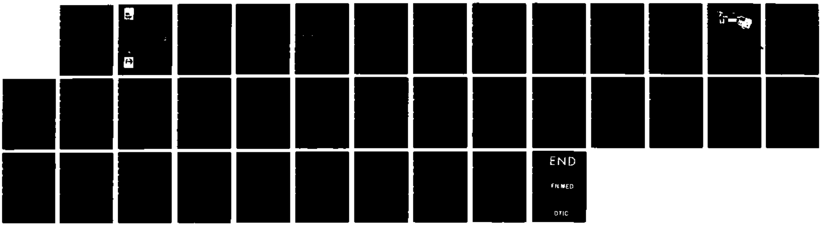

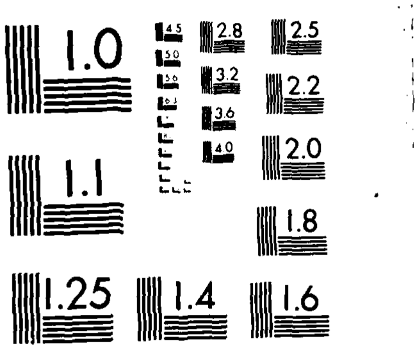

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ENVIRONMENTAL AND WATER QUALITY OPERATIONAL STUDIES

TECHNICAL REPORT E-85-1

REAERATION AT NAVIGATION LOCKS

by

Steven C. Wilhelms

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631
Vicksburg, Mississippi 39180-0631

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Gas transfer at several Corps of Engineers navigation locks was evaluated relative to effects on downstream dissolved oxygen and dissolved nitrogen concentrations. In-lock measurements indicated that very little oxygen uptake occurred during lock filling. Measurements of dissolved oxygen in the release water indicated that, in general, lock releases improve or maintain existing downstream water quality. At some locks where the downstream bulkhead slots were open to the atmosphere, significant air entrainment occurred

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20. ABSTRACT (Continued)

downstream of the emptying valve during releases. The air and water mixture and hydraulic conditions in the downstream release conduits caused significant oxygen uptake and even oxygen supersaturation. Simultaneously, nitrogen supersaturation occurred but at levels that did not appear to be detrimental to aquatic biota.

Preface

The prototype tests and data analyses described herein were authorized by the US Army Engineer Division, South Atlantic, at the request of the US Army Engineer District, Mobile (SAM). The studies were conducted by personnel of the Hydraulics Laboratory of the US Army Engineer Waterways Experiment Station (WES) during the period November 1980 to March 1981 under the direction of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and J. L. Grace, Jr., Chief of the Hydraulic Structures Division. Dr. D. R. Smith and Mr. J. P. Holland, Chiefs of the Reservoir Water Quality Branch, supervised the study and the preparation of this report. Messrs. C. H. Tate, Jr., and S. C. Wilhelms conducted the field tests and data analyses. Mr. H. R. Smith assisted in the field data collection. Mr. Wilhelms prepared this report. The outstanding cooperation and assistance given by the lockmasters, operators, and resource managers at the various projects of the US Army Engineer Districts, Mobile and Nashville, are acknowledged and appreciated.

During the course of the study, Messrs. Henry A. Malec, Jack G. Ward, and Howard M. Whittington, SAM, visited WES to discuss tests and data analyses and correlate these results with concurrent plan and design of navigation locks proposed for the Coosa River, Ala.

The approach, instrumentation, and capability employed were developed by prior Hydraulics Laboratory research conducted under the Environmental and Water Quality Operational Studies (EWQOS) Work Unit IIIA.1, "Evaluate Field Reaeration Data at Existing Structures," which was sponsored by the Office, Chief of Engineers (OCE). The OCE Technical Monitors for EWQOS were Dr. John Bushman, Mr. Earl Eiker, and Mr. James L. Gottesman. Dr. Jerome L. Mahloch of WES was Program Manager of EWQOS.

Commanders and Directors of WES during these studies and the preparation and publication of this report were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

This report was published under EWQOS Work Unit IIIA.3, "Aeration/Oxygenation of Hydropower Releases," and should be cited as follows:

Wilhelms, S. C. 1985. "Reaeration at Navigation Locks," Technical Report E-85-1, US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Contents

REAERATION AT NAVIGATION LOCKS

Introduction

1. The energy stored behind a dam provides an opportunity to improve the dissolved oxygen (DO) concentration of release water. Dissipation of the energy during release creates turbulence and mixing and can induce an oxygen uptake. The increasing demand on our nation's water resources for recreation, commerce, and water supply dictates that every available opportunity be used to maintain or improve water quality. These opportunities to enhance release DO must be exploited to their fullest to ensure that high quality water is available. Many navigable rivers are impounded with relatively low-head, run-of-the-river dams with locks for passage of boats and barges. Almost no data are available in the literature to qualitatively or quantitatively describe the impact of locks upon downstream DO. It is speculated that the operation of a navigation lock will tend to enhance the downstream DO concentration, especially if air is entrained in the release and significant turbulence occurs during emptying. If lock operations provide a significant portion of the total streamflow, the downstream water quality may be substantially improved.

Purpose and Scope

2. The purpose of this effort was to evaluate and document the impact of lock releases upon downstream DO concentrations. To accomplish this objective, 11 Corps of Engineers (CE) locks were evaluated in field studies during 1981 and 1982. The projects visited during the field studies were:

Project	River	CE District
Demopolis Lock	Warrior	Mobile
Holt Lock	Warrior	Mobile
Bankhead Lock	Warrior	Mobile

(Continued)

Project	River	CE District
Walter F. George Lock	Chattahoochee	Mobile
Claiborne Lock	Alabama	Mobile
Gainesville Lock	Tombigbee	Mobile
Aliceville Lock	Tombigbee	Mobile
Guntersville Lock	Tennessee	Nashville
Wheeler Lock	Tennessee	Nashville
Wilson Lock	Tennessee	Nashville
Pickwick Lock	Tennessee	Nashville

The results of these studies are presented in subsequent paragraphs.

Lock Geometry and Hydraulic Conditions

3. The locks that were evaluated varied in size and lift. Typically, they were 600 ft (183 m) long and 110 ft (34 m) wide. Lifts varied from about 30 ft (9 m) to almost 100 ft (30 m). Water from the upper pool was drawn into ports either between the upstream guidewalls or outside the guidewalls and then distributed in the lock chamber by a side-port or bottom diffuser system. Lock water was discharged either between the downstream guidewalls through a side-port discharge manifold, outside the downstream guidewalls through a side-port discharge manifold, or through a stilling basin outside the downstream guidewalls.

4. During filling, hydraulic conditions in the lock chambers were reasonably smooth since turbulence within the lock is undesirable for navigation. During the first minutes of the filling operation, at some locks, air was aspirated into the inflow through air vents downstream of the filling valves. This was evidenced by the appearance of air bubbles in the lock chamber. This aspiration was usually controlled with a gate valve, since large volumes of air could create adverse turbulence in the lock chamber. As water in the lock chamber rose, hydraulic pressures downstream of the filling valves became sufficiently large to cease aspiration.

5. During emptying, the downstream discharge area was extremely turbulent. High velocities and large boils were typical of lock discharge areas whether located outside the guidewalls or between the guidewalls. Generally, air vents are not provided for the emptying valves and, at some locks, the downstream bulkhead slots are sealed. However,

at some locks, the bulkheads were open and a large amount of air was aspirated into the outflow during all or part of the emptying cycle. This was evident from the frothy appearance of the outflow boil. The downstream pool elevation remained essentially constant and the emptying valve was relatively unsubmerged. Thus, flow conditions at the valve caused air entrainment during a large portion of the emptying cycle. When the air/water mixture traveled through the outlet conduit, increased hydrostatic pressure created a thermodynamic state that significantly enhanced oxygen uptake. However, dissolved nitrogen (DN) was simultaneously transferred to the release water, resulting in slight nitrogen supersaturation. These data are discussed in subsequent paragraphs.

Measurement Location and Equipment

6. Measurements of DO and temperature were taken in the lock chamber to evaluate the gas transfer during the filling cycle. Total dissolved gas pressure (TDGP) was also measured at selected projects. Probes were positioned off the side of the survey boat near the center of the lock chamber at a 10-ft (3-m) depth as the chamber filled. Release DO, temperature, and TDGP were monitored during emptying, from as close to the discharge area as practicable. The survey boat was either tied to the guidewalls or anchored a short distance from the discharge outlet. In either location, care was taken to ensure that mainstream flow was monitored.

7. A Yellow Springs Instrument (YSI) Model 57 dissolved oxygen meter was used to monitor temperature and DO concentrations. Esterline-Angus stripchart recorders were used to record the oxygraphs during filling and emptying operations. The U. S. Army Engineer Waterways Experiment Station (WES) saturometer (Figure 1), which incorporates a YSI temperature and DO probe, was used when TDGP was measured.

Data and Analysis

8. Since the locks were not hydrodynamically similar, the data from each merit individual consideration. The observed data are

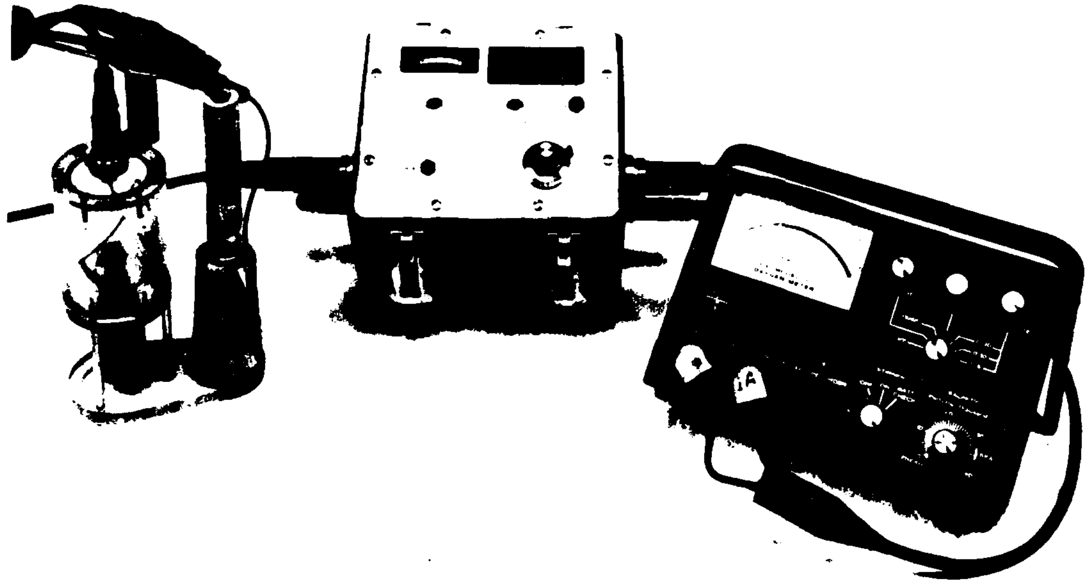


Figure 1. WES saturometer and dissolved oxygen meter

presented and discussed on a lock-by-lock basis in the following paragraphs.

Oxygen transfer.

9. Holt Lock. Figure 2 shows the lock filling oxygraph. The DO increase was due to air aspiration but was apparently insignificant in affecting the overall DO content in the lock chamber. This was typical of the in-lock oxygraph in that reaeration during filling tended to have negligible effects upon the final in-lock DO concentration. Water temperature was 29.0° C. Figure 3 shows the oxygraphs of releases from Holt Lock. The downstream background DO concentration was 5.9 mg/ℓ. The peak DO during the lock release was 6.5 mg/ℓ compared to the in-lock concentration of 4.5 mg/ℓ. This indicates significant reaeration occurred during emptying, although air aspiration during emptying was minimal. Even though the in-lock concentration was 1.4 mg/ℓ less than the downstream concentration, reaeration was sufficiently large that no degradation occurred due to lock operation.

10. Wilson Lock. In-lock water temperature was 27.2° C. In-lock DO was 4.6 mg/ℓ even though aspiration during filling caused an increase to 5.8 mg/ℓ for a short period (Figure 4). Downstream DO prior to the

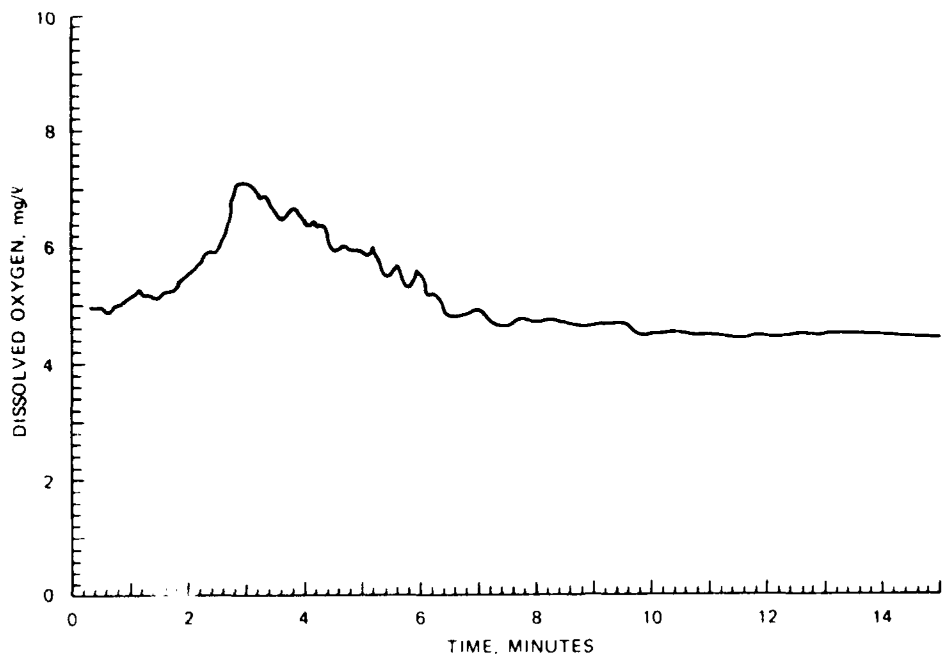


Figure 2. Holt Lock filling oxygraph

lockage was 5.7 mg/ℓ. Release DO for the first test peaked at 7.8 mg/ℓ (Figure 5a). This oxygen uptake was apparently due to reaeration induced by turbulence in the discharge area because air aspiration at the emptying valve appeared negligible. Downstream background DO was 6.8 mg/ℓ due to retention of previously released water but peak DO was again 7.8 mg/ℓ (Figure 5b) for a second lock emptying about 30 min after the first. Reaeration due to turbulence during emptying significantly improved the DO regime downstream of Wilson Lock. These figures also demonstrate the reproducibility of the processes causing reaeration: the peak DO concentrations were identical (nearly reaching saturation at 8.0 mg/ℓ) even though downstream background DO was significantly greater for the second test. Data reproducibility was characteristic of the locks that were evaluated.

11. Wheeler Lock. The gas transfer at Wheeler Lock was similar to that of Wilson and Holt Locks in that reaeration during emptying caused the downstream DO to increase from 5.8 mg/ℓ (in-lock and

conditions (i.e., different pool elevations or slightly different lock operations) or the higher in-lock DO of the 1981 tests compared to those of 1982. However, for either set, it is evident that air entrainment downstream of the emptying valve contributed significantly to the oxygen uptake.

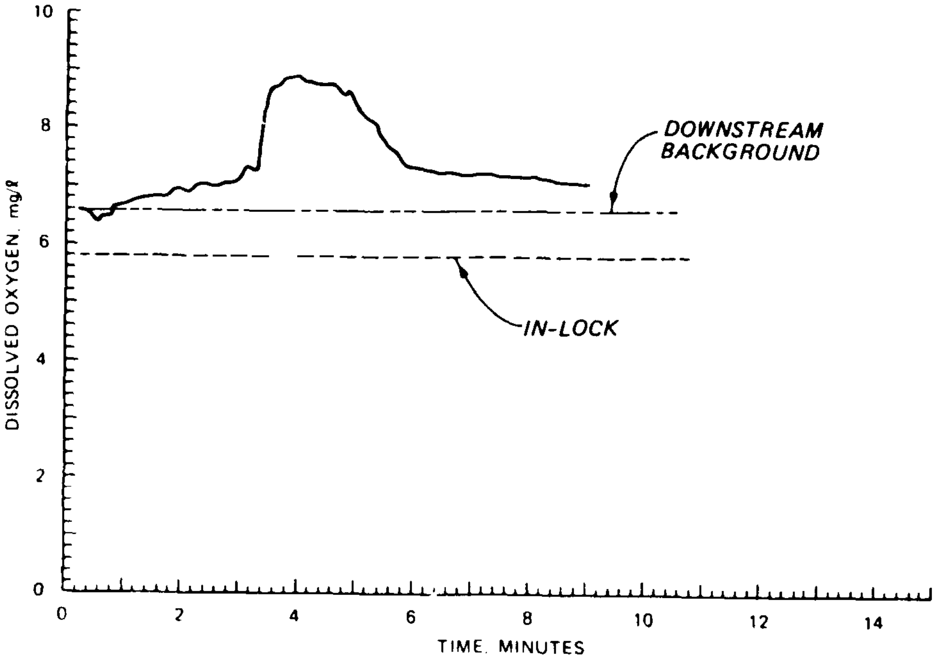
21. Demopolis Lock. Figure 14 shows oxygraphs of releases from Demopolis Lock during 1981 testing. The DO level in the lock chamber was 6.4 mg/ℓ with no change during filling. The water temperature was 31.2° C. Air was entrained into the releases, which caused release DO to peak at approximately 8 mg/ℓ. The downstream background DO was improved slightly by the first lockage test from 5.2 mg/ℓ to 5.6 mg/ℓ. The peak release concentration during the second lock operation was approximately 8 mg/ℓ, the same as the first test. Similar results were noted earlier for Wilson Lock.

22. For each of the four consecutive tests conducted in 1982 (Figure 15), the downstream background DO was about 5.4 mg/ℓ with water temperature at 33.5° C. Peak DO concentrations in the release were as high as 8.4 mg/ℓ. These peak DO levels, as well as those indicated by the oxygraphs in Figure 15, show that air aspiration and hydraulic conditions existed that resulted in oxygen supersaturation.

23. Pickwick Lock. Operation of Pickwick Lock also resulted in significant oxygen uptake into the release. For the 1981 tests shown in Figure 16, the DO concentration downstream was 6.4 mg/ℓ and 7.0 mg/ℓ. In-lock DO was 7.9 mg/ℓ; temperature was 27.7° C. The peak DO concentration was approximately 9.2 mg/ℓ, indicating that reaeration had a significant impact on release DO. Very similar results were obtained for the 1982 tests shown in Figure 17. The peak release DO concentration was approximately 9.2 mg/ℓ. Downstream DO was 7.2 mg/ℓ. In-lock DO was about 7.8 mg/ℓ with a water temperature of 26.8° C. The large amount of air that was entrained into the flow during emptying and the hydrostatic pressure in the conduits were the apparent causes of the large DO uptake.

Nitrogen transfer

24. Based on the measured oxygen uptake during the 1981 field tests, Demopolis, Guntersville, and Pickwick Locks were selected for



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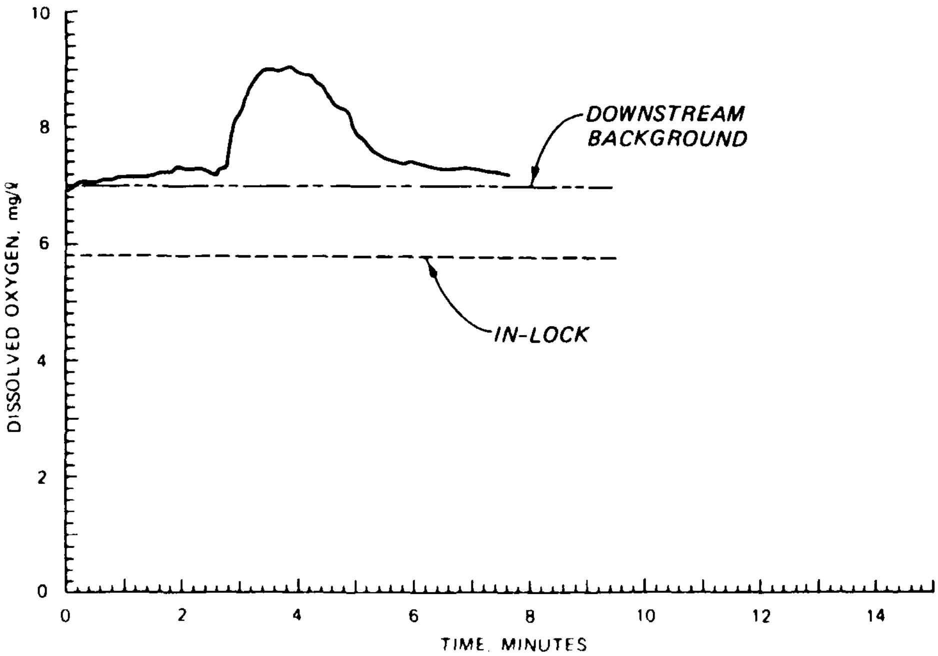

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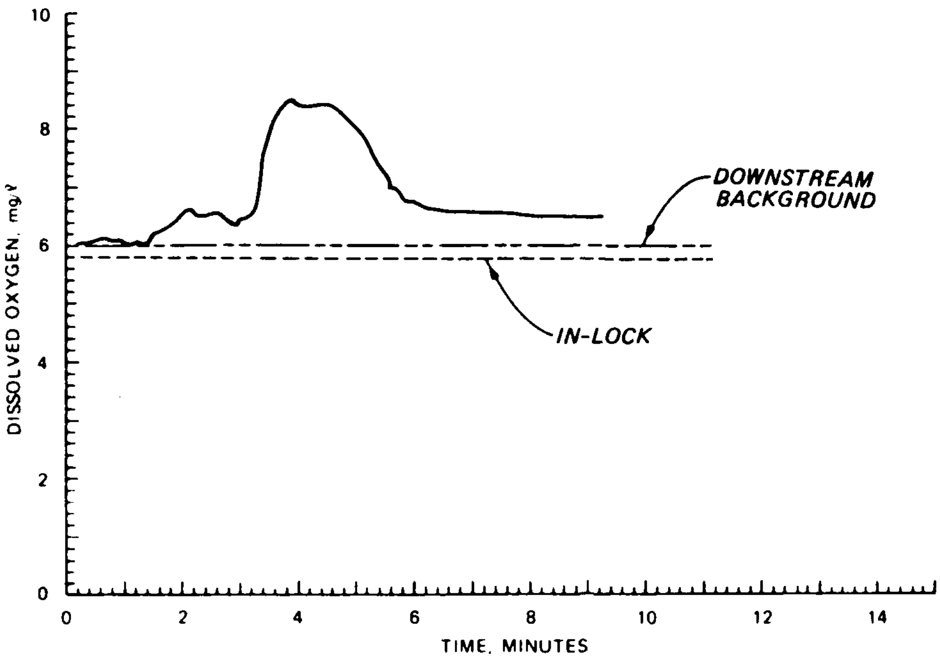

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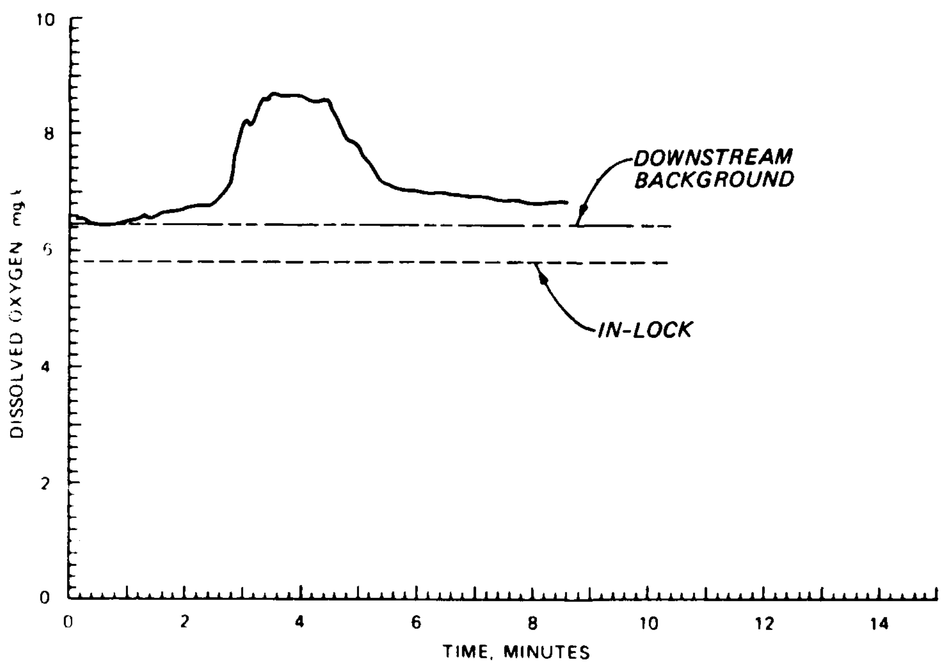
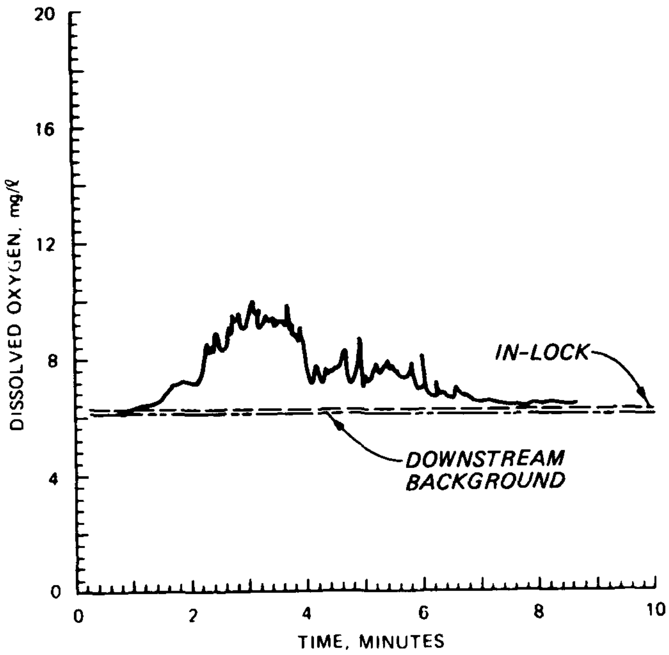


b. Test 2

Figure 13. Guntersville Lock emptying oxygraphs, 1982 (Continued)



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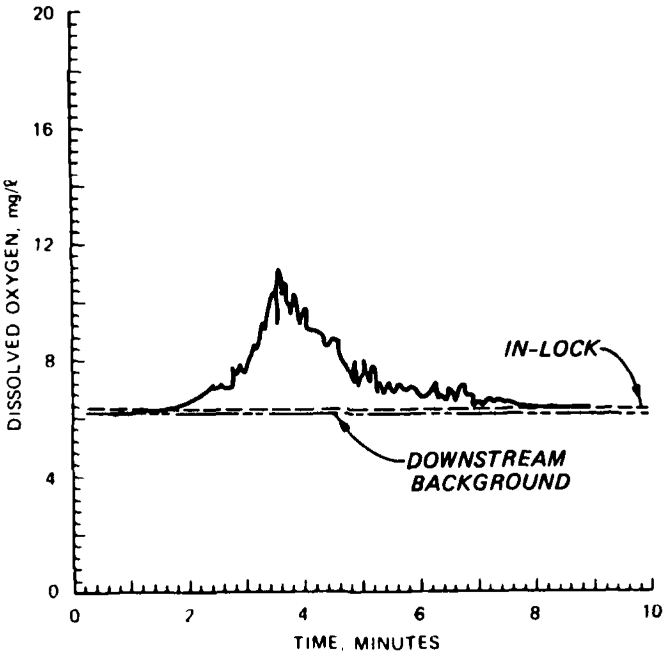


b. Test 2

Figure 12. Guntersville Lock emptying oxygraphs, 1981

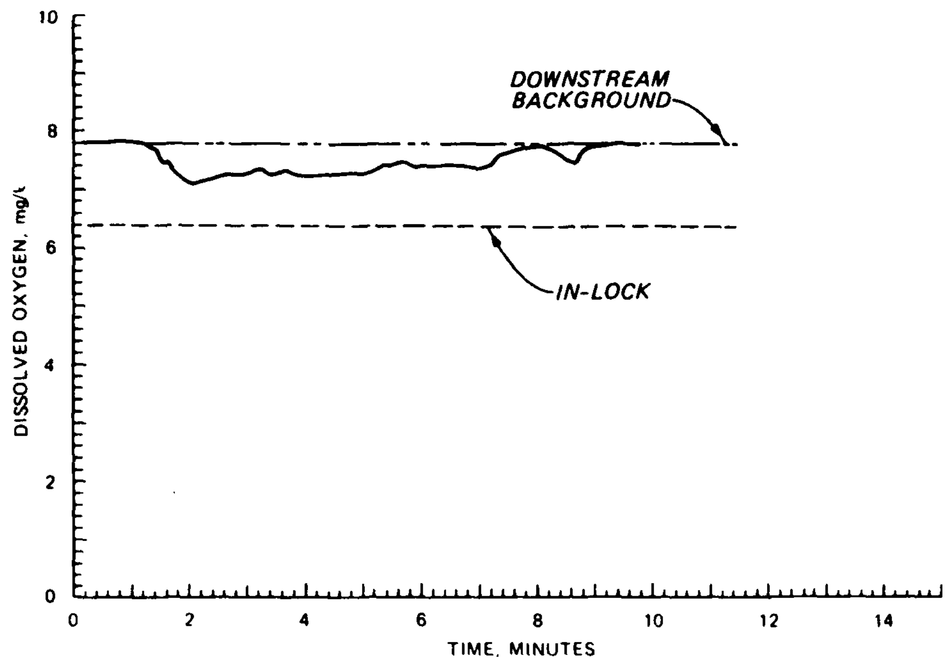


Figure 11. Claiborne Lock emptying oxygraph

1981 Guntersville Lock operations. The downstream background DO concentration for these tests was 6.1 mg/ℓ and the temperature was 26.8° C. In-lock DO was 6.3 mg/ℓ and the peak DO concentration during lock emptying was above 10 mg/ℓ, indicating large oxygen uptake and even oxygen supersaturation. The release water was frothy-white with air bubbles indicating that air entrainment downstream of the emptying valves was very significant. The hydrostatic pressure in the release conduits downstream of the emptying valves apparently caused the large uptake and oxygen supersaturation.

20. Results of 1982 field testing showed the downstream background DO concentration to be approximately 6.0 mg/ℓ for the first test (Figure 13a) and nearly 7.0 mg/ℓ (due to retention of released water in the area) during the final test (Figure 13d). In-lock DO was about 5.8 mg/ℓ for all four 1982 tests; temperature was 25.9° C. Peak concentrations for these tests ranged from 8.5 mg/ℓ to 9.0 mg/ℓ, which is more than 1 mg/ℓ less than the peaks observed in the 1981 tests shown in Figure 12. It is not clear why the peak release DO was higher for one set of tests compared to the other. This may have been caused by different hydraulic

concentration. Very little air was aspirated into the release flow and, since in-lock DO was relatively high, it was concluded that the improvement in DO in the tailrace was due to releasing water with a high DO concentration.

16. Gainesville Lock. At Gainesville Lock, very little oxygen uptake was observed because the in-lock DO was just above saturation, causing any reaeration to be undetectable. In-lock DO and temperature were 8.1 mg/ℓ and 32° C, respectively. Downstream background DO was 6.7 mg/ℓ. Due to mixing of these waters, the peak DO concentration measured in downstream releases was approximately 7.6 mg/ℓ.

17. Aliceville Lock. Essentially no oxygen uptake occurred at Aliceville Lock. The in-lock DO concentration was approximately 3.3 mg/ℓ. In-lock water temperature was 30.3° C. The downstream background and release DO were about 3.2 mg/ℓ. There was no noticeable aspiration of air into the release flow, and turbulence in the release area (between the downstream guidewalls) was minimal. The downstream DO concentration was unaffected by the lock release.

18. Claiborne Lock. Discharge from Claiborne Lock, which was through a side-port system, immediately mixed with spillway releases. The DO concentration below the spillway (downstream background) was 7.8 mg/ℓ, and in-lock DO was 6.4 mg/ℓ. Water temperature was 32.1° C. Figure 11 shows the release oxygraph. Very little oxygen uptake apparently occurred during emptying. The "sag" in the oxygraph is due to mixing of the in-lock water with spillway release. These results indicate that lock operations at this particular location may result in releases with less DO than downstream background. This occurred because the release over the spillway was highly aerated, which resulted in a near-saturation DO concentration downstream. Reaeration through the hydraulic system of the lock cannot match the level of reaeration that occurs with discharge over a spillway and through a stilling basin. However, at low river stages, when the spillway is not in use, lock releases should affect downstream DO concentration in a manner similar to Bankhead, Gainesville, or Aliceville Lock.

19. Guntersville Lock. Figure 12 shows release oxygraphs for

lower peak was apparently the result of mixing of lock release water with the lower DO power release water.

14. The background DO without power generation (Figure 8) was lower than downstream background with power releases. This was indicative of effects of a long residence time of releases in the tailwater area. The without-power tests were conducted in the early morning. Prior to these tests, the entire project was subjected to an extended period of inactivity. Thus, the last releases, whether lock or power discharges, were retained in the downstream area. Oxygen-demanding material could have a significant impact in reducing the downstream background DO. However, even with the varying circumstances under which Walter F. George Lock was tested, releases from the lock improved downstream DO.

15. <u>Bankhead Lock</u>. Figure 10 shows the Bankhead Lock release oxygraph. The downstream background DO was 5.6 mg/ℓ (due to hydropower releases) and the in-lock concentration was 6.4 mg/ℓ. In-lock water temperature was 27.9° C. The DO concentration in the lock release peaked at approximately 6.2 mg/ℓ, which was very close to the in-lock DO

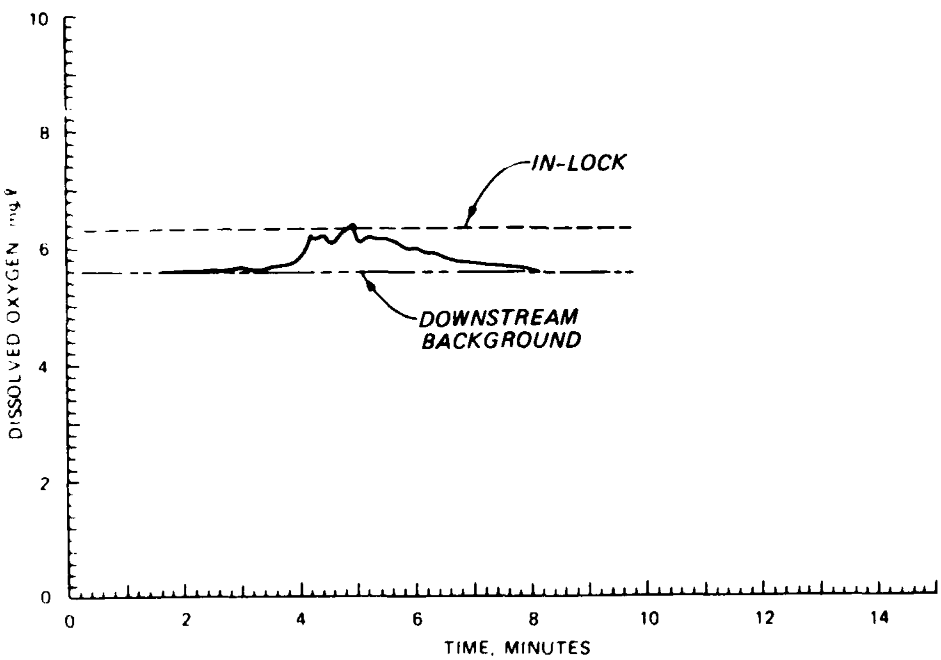
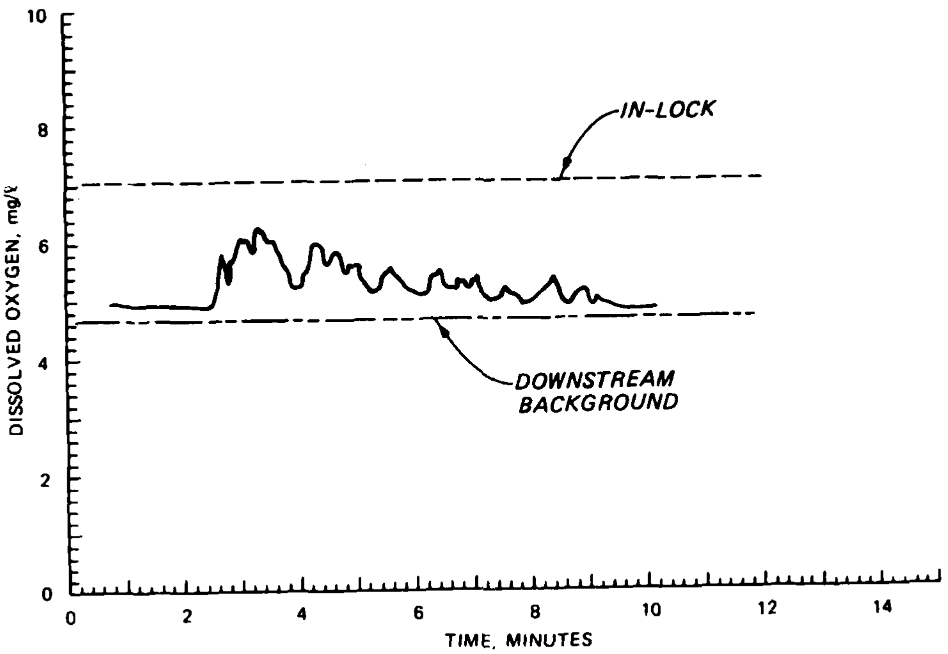


Figure 10. Bankhead Lock emptying oxygraph



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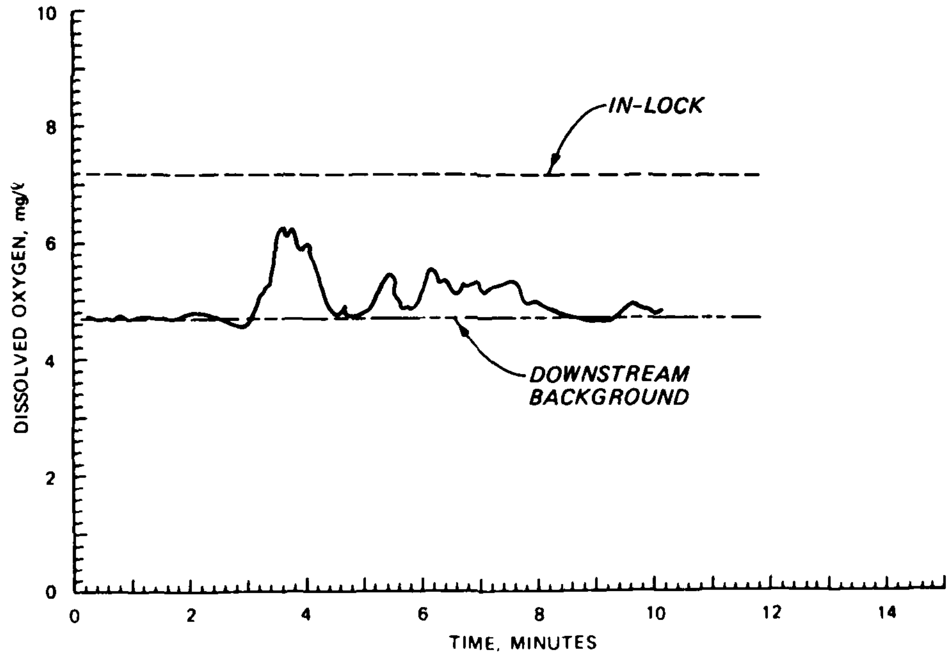

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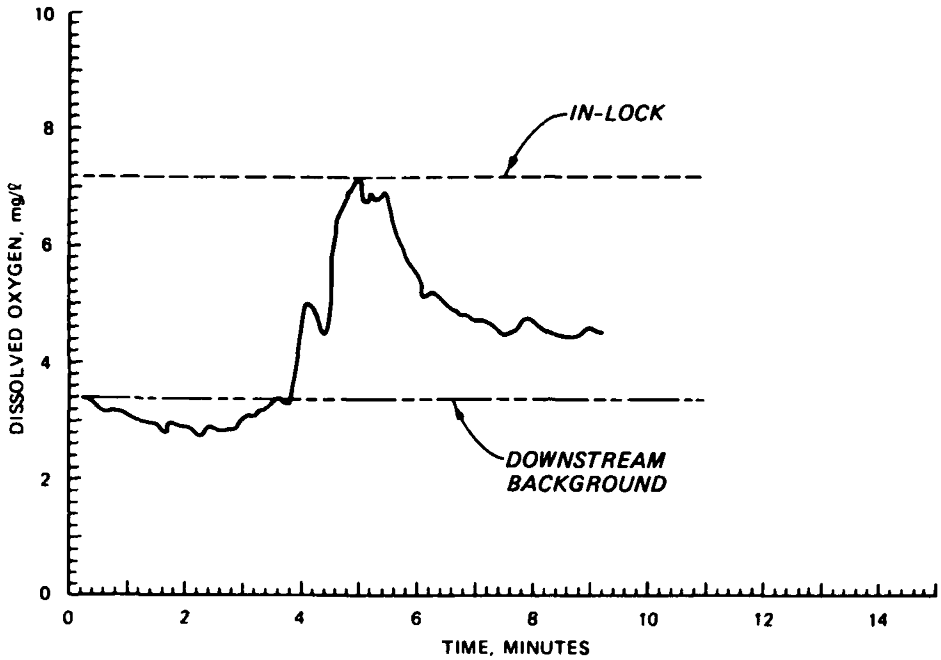
Figure 9. Walter F. George Lock emptying oxygraphs with power generation, 1982



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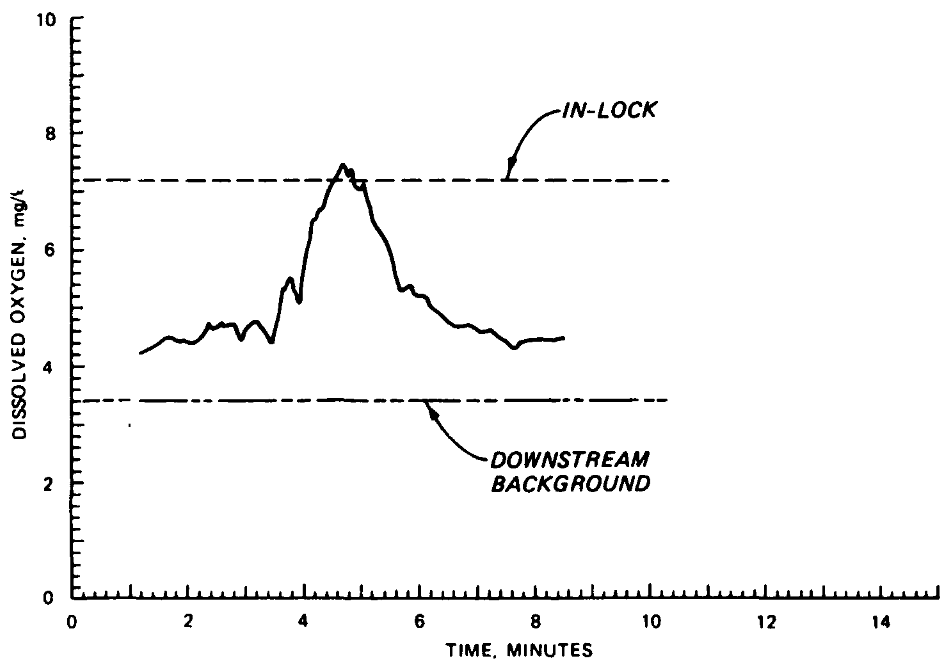

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Figure 8. Walter F. George Lock emptying oxygraphs without power generation, 1982

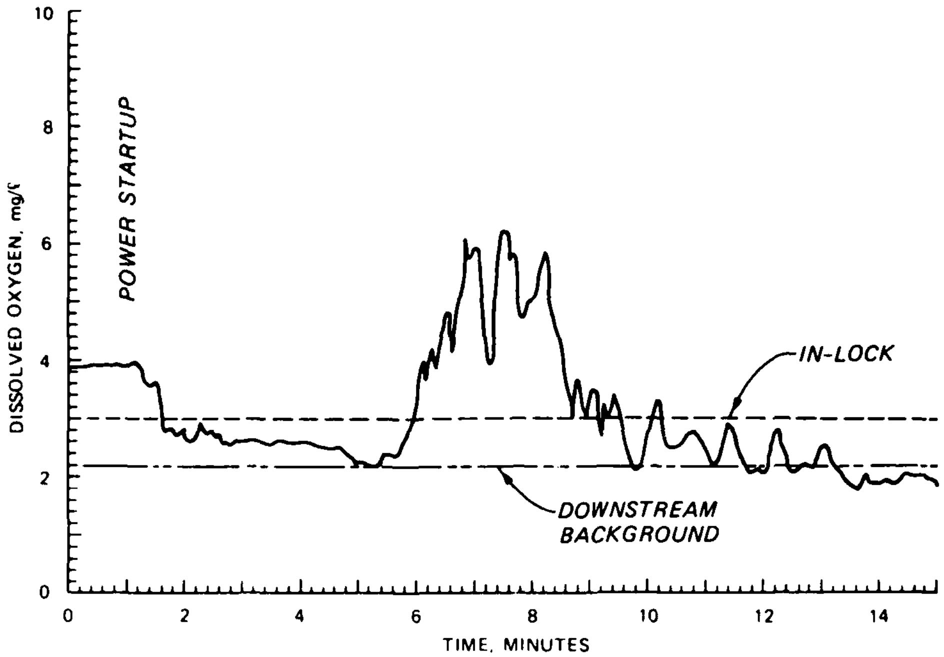
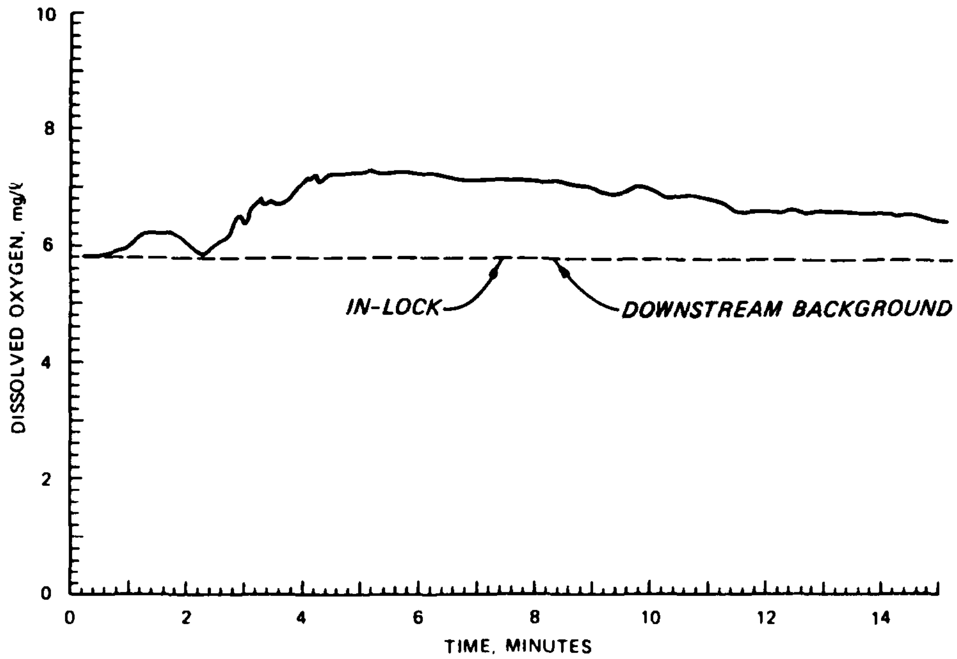


Figure 7. Walter F. George emptying oxygraph with power generation and lake turnover, 1980

air aspiration was not significant) to produce a peak DO concentration of approximately 5.2 mg/ℓ.

13. The in-lock DO for the oxygraphs shown in Figure 8 was 7.2 mg/ℓ. Water temperature was 29.4° C. There were no hydropower releases at the time of these tests. Downstream background DO was approximately 3.4 mg/ℓ. The peak DO concentration during release was 7.2 mg/ℓ, which corresponds to the lock concentration, indicating that very little reaeration occurred during the emptying of the lock. This was expected since very little air was aspirated into the release and the high in-lock DO would preclude a large DO uptake. Downstream DO improved due to the release of water higher in quality than the downstream background quality. Figure 9 shows the release oxygraphs for lock emptying during hydropower releases. Downstream background DO was approximately 4.6 mg/ℓ, in-lock background was 7.2 mg/ℓ, and peak release DO concentration was 6.2 mg/ℓ. The peak DO was not as high as it was without the power releases, although the in-lock concentration was the same. The



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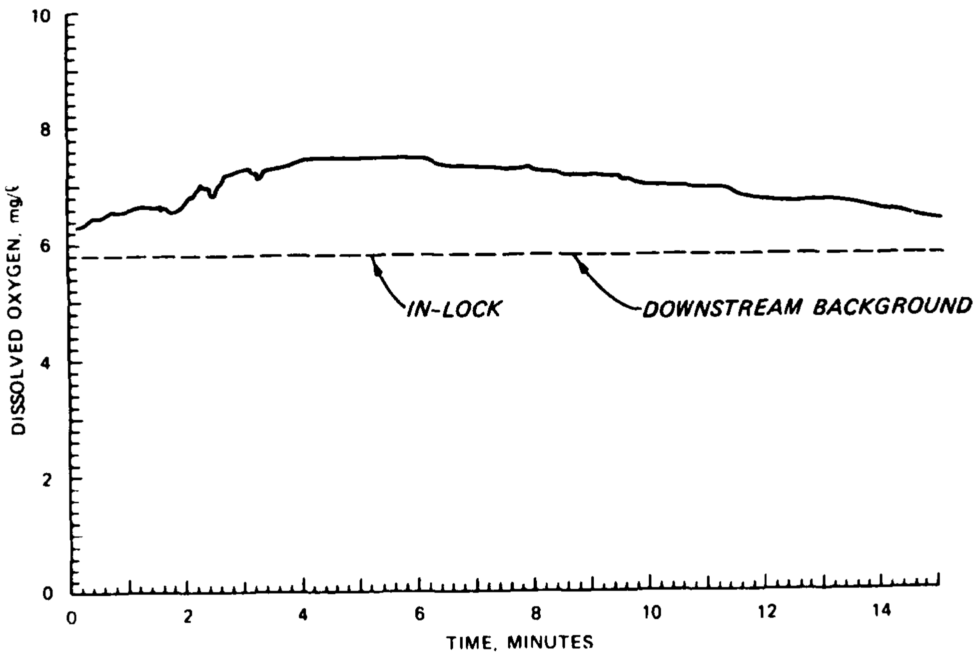

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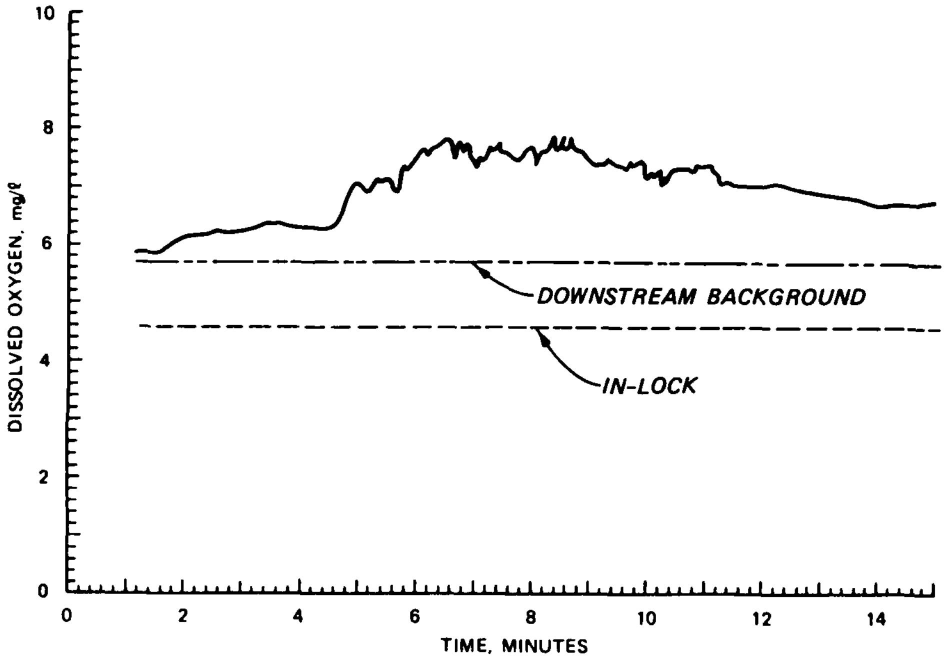
Figure 6. Wheeler Lock emptying oxygraphs



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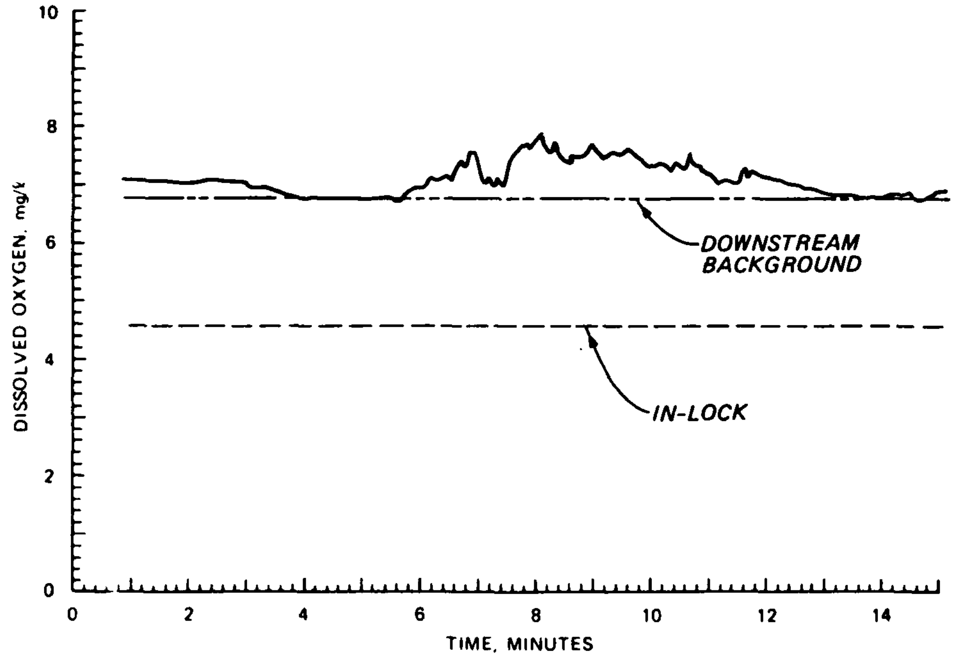

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Figure 5. Wilson Lock emptying oxygraphs

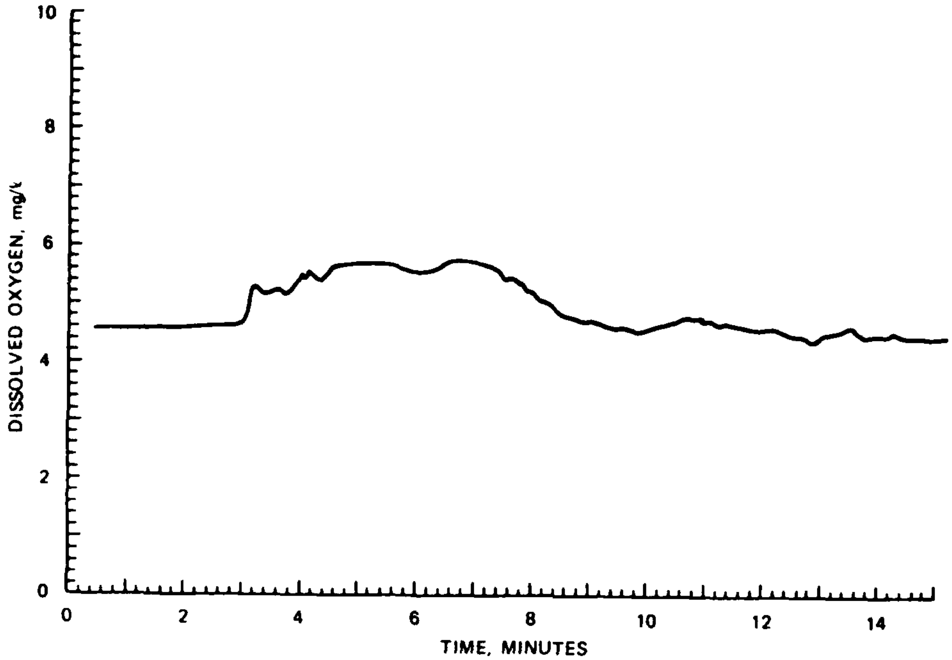
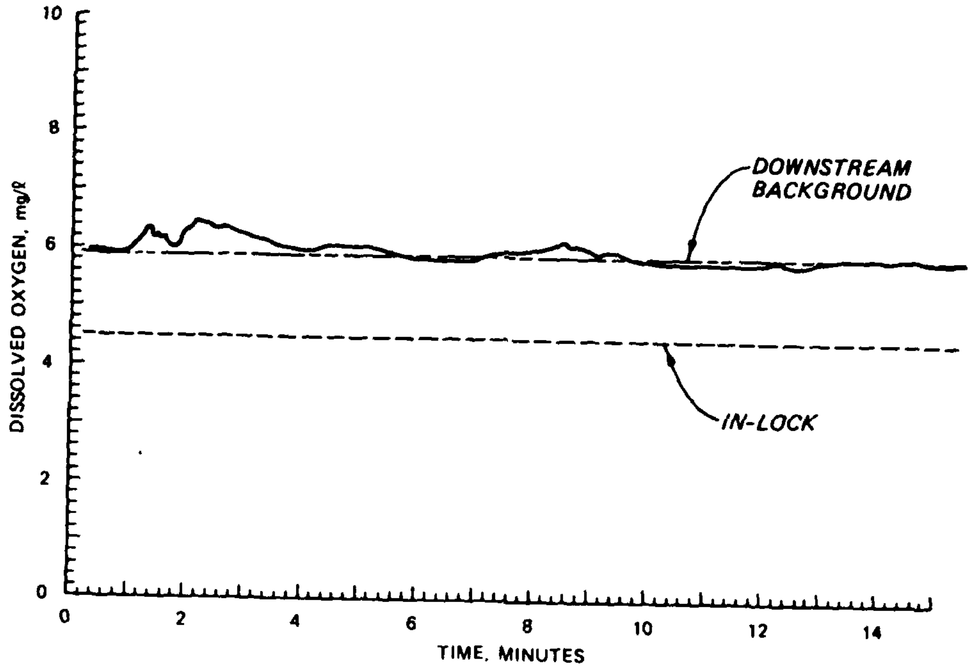


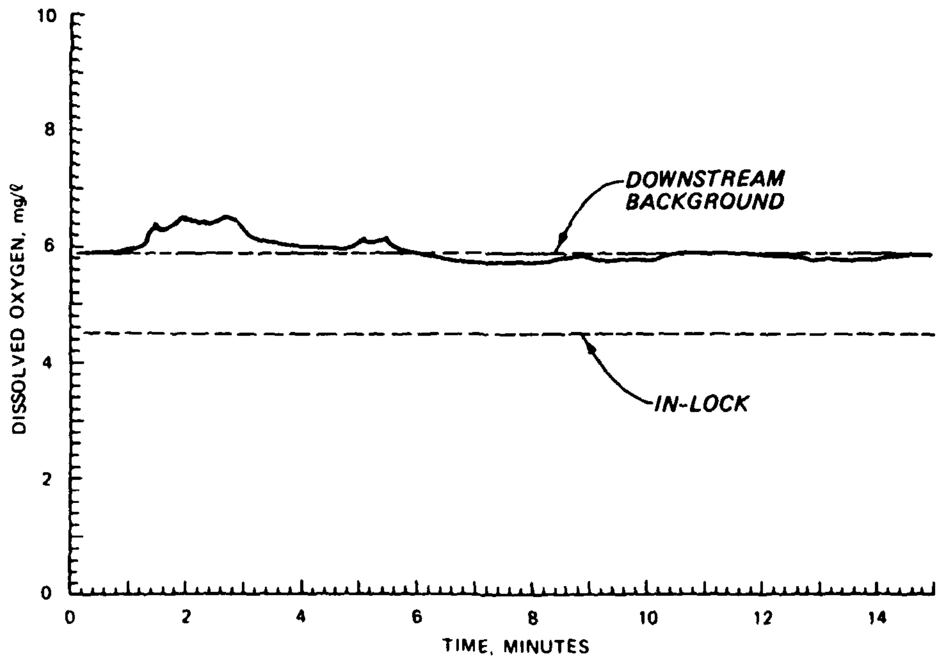
Figure 4. Wilson Lock filling oxygraph

downstream background level) to a peak of 7.2 mg/ℓ (Figure 6). Again the aspiration of large volumes of air was not apparent. Thus, just as at Holt and Wilson Locks, the gas transfer appeared to be the result of turbulence during release. The hydraulics of the area outside the energy dissipation basin caused circulation and long retention of release water. Since the oxygenated release water did not flow downstream immediately, the oxygraphs were extended.

12. Walter F. George Lock. Water temperature was 28.2° C. In-lock DO for the release oxygraph illustrated in Figure 7 was 3.0 mg/ℓ. It is speculated that the low DO in the lock was the result of lake "turnover" caused by a severe storm system that passed through the area prior to this test, particularly when compared to the relatively high surface DO, strong oxycline, and high lock DO observed in subsequent tests. The turnover caused the lake DO to decrease to 4.2 mg/ℓ and below. Downstream background was about 3.8 mg/ℓ until power generation began. The downstream DO then decreased to about 2.2 mg/ℓ. There was sufficient reaeration during lock emptying (primarily due to turbulence;

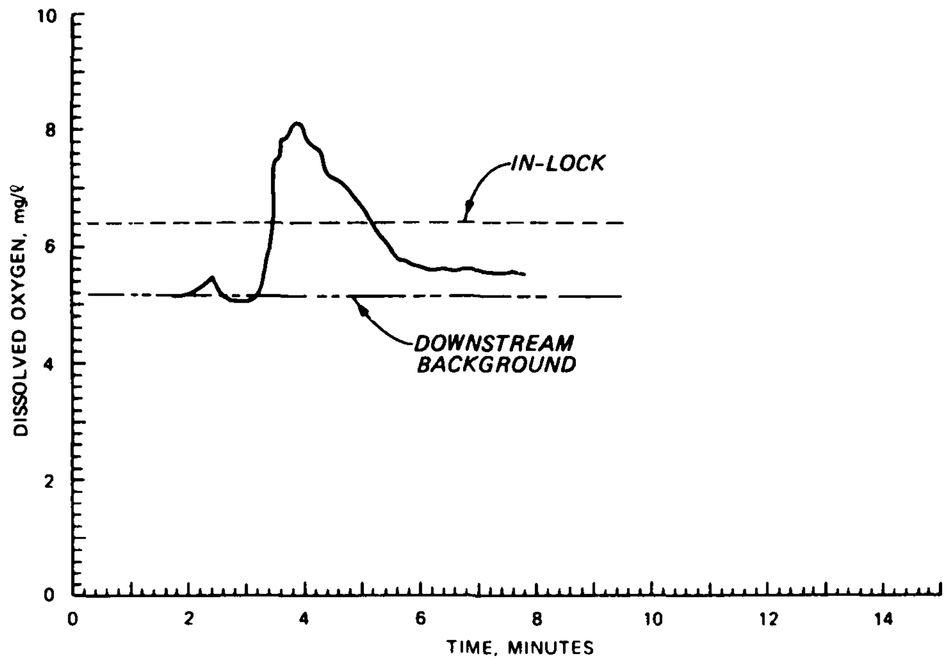


a. Test 1

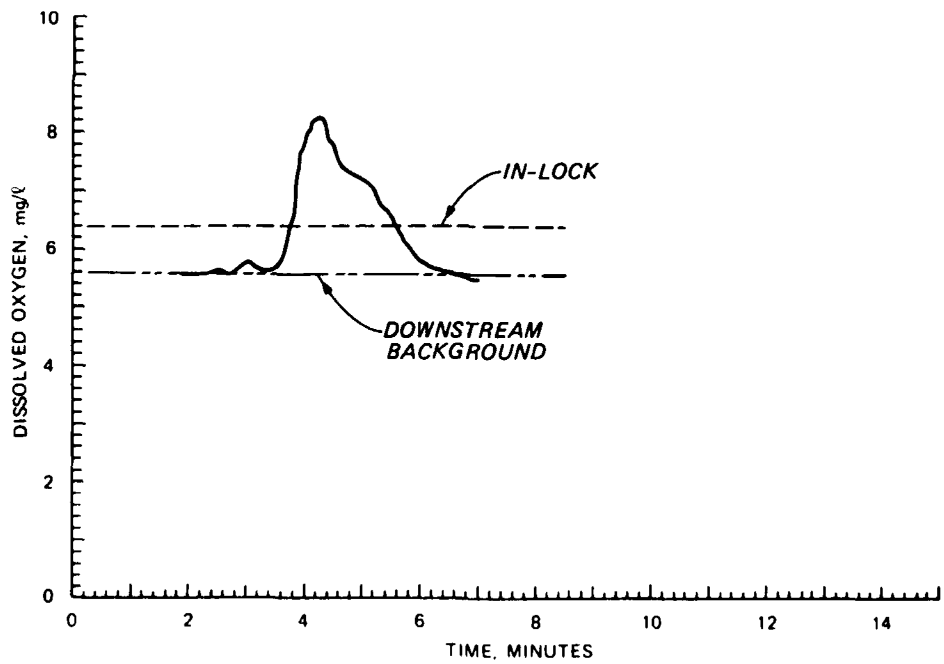


b. Test 2

Figure 3. Holt Lock emptying oxygraphs

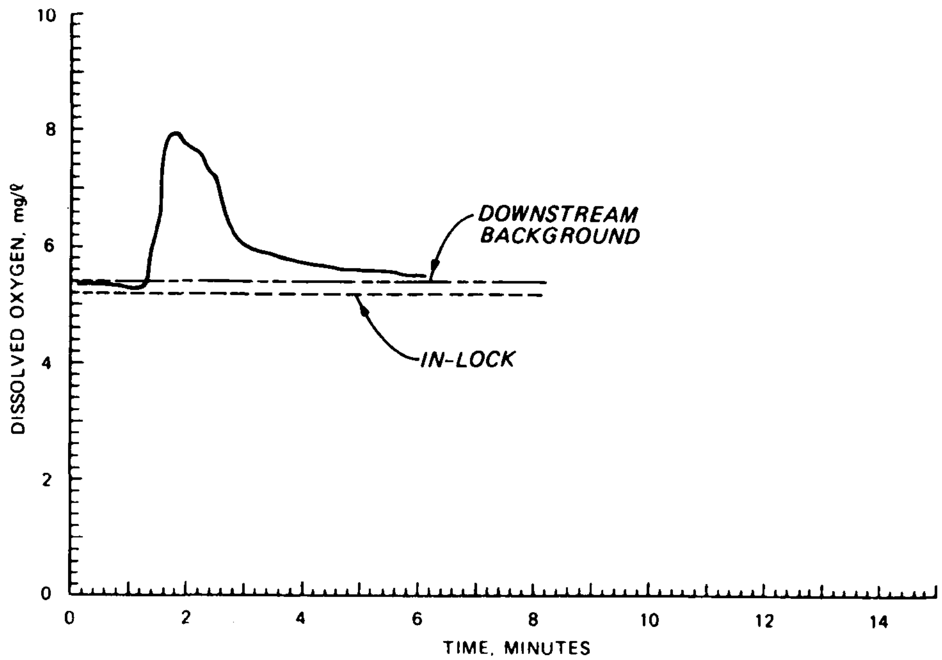


a. Test 1

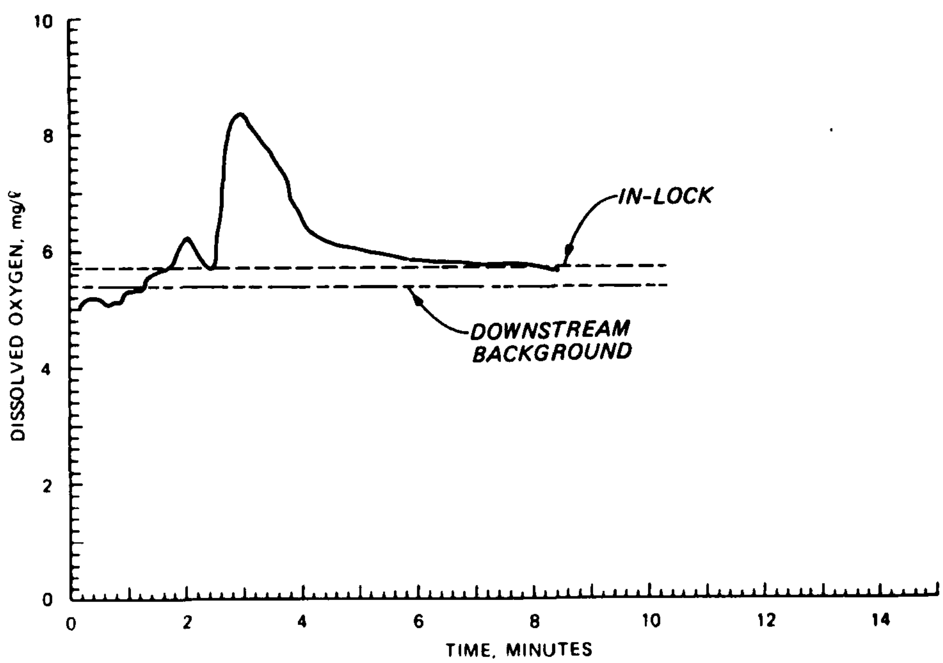


b. Test 2

Figure 14. Demopolis Lock emptying oxygraphs, 1981

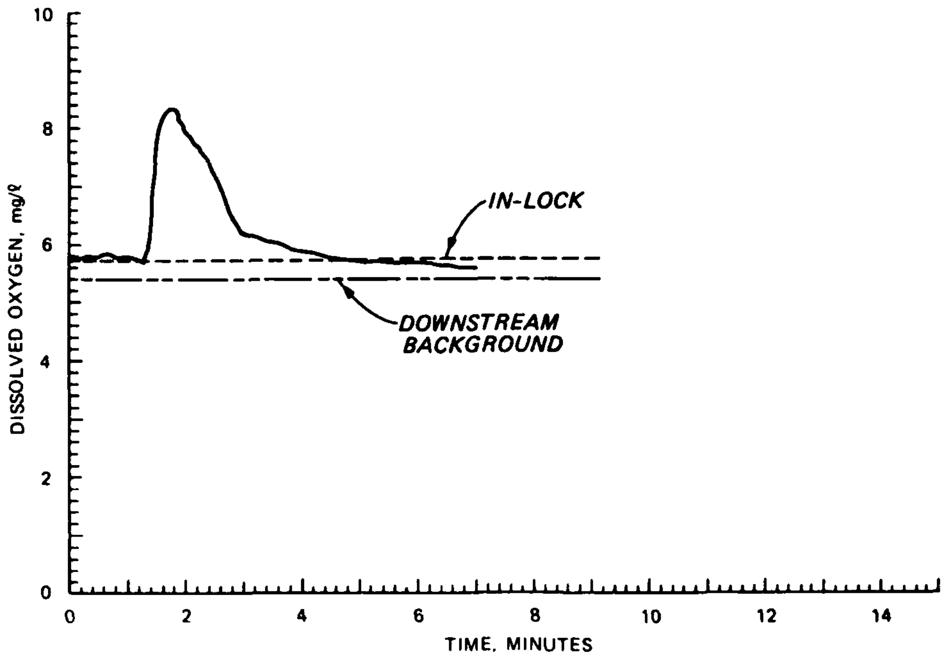


a. Test 1

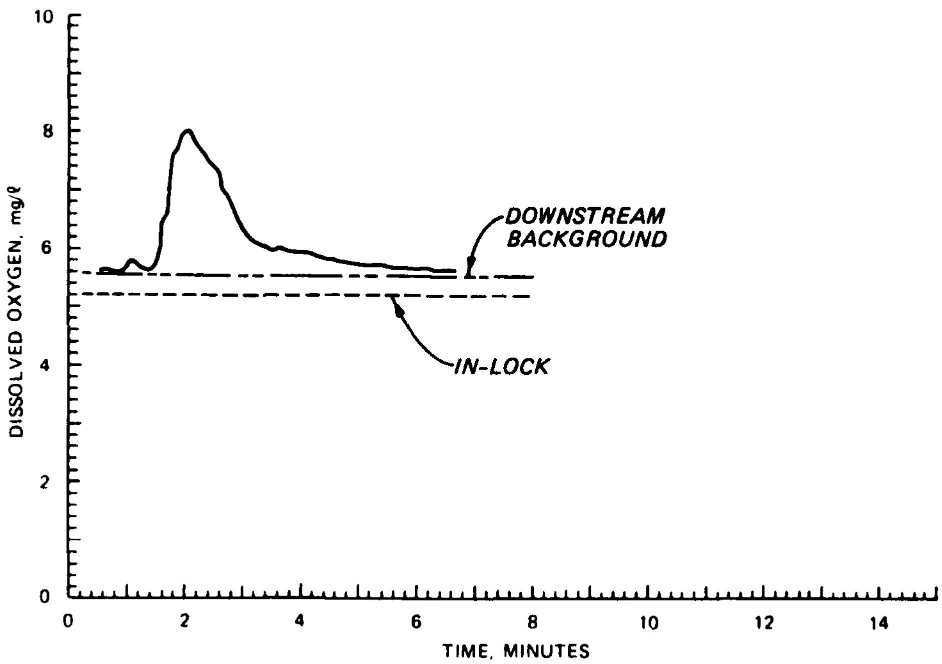


b. Test 2

Figure 15. Demopolis Lock emptying oxygraphs, 1982 (Continued)

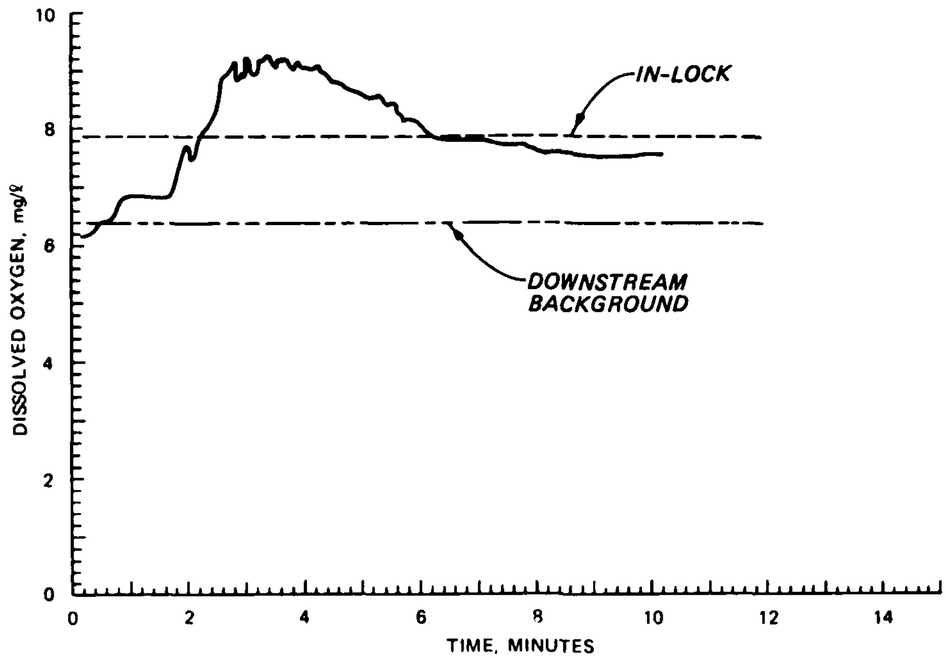


c. Test 3

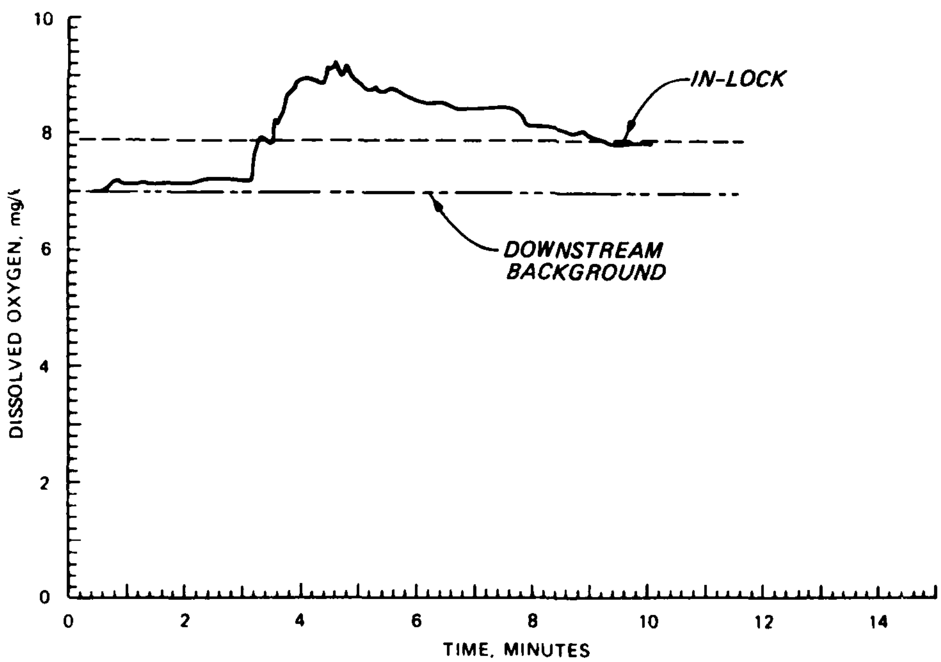


d. Test 4

Figure 15. (Concluded)

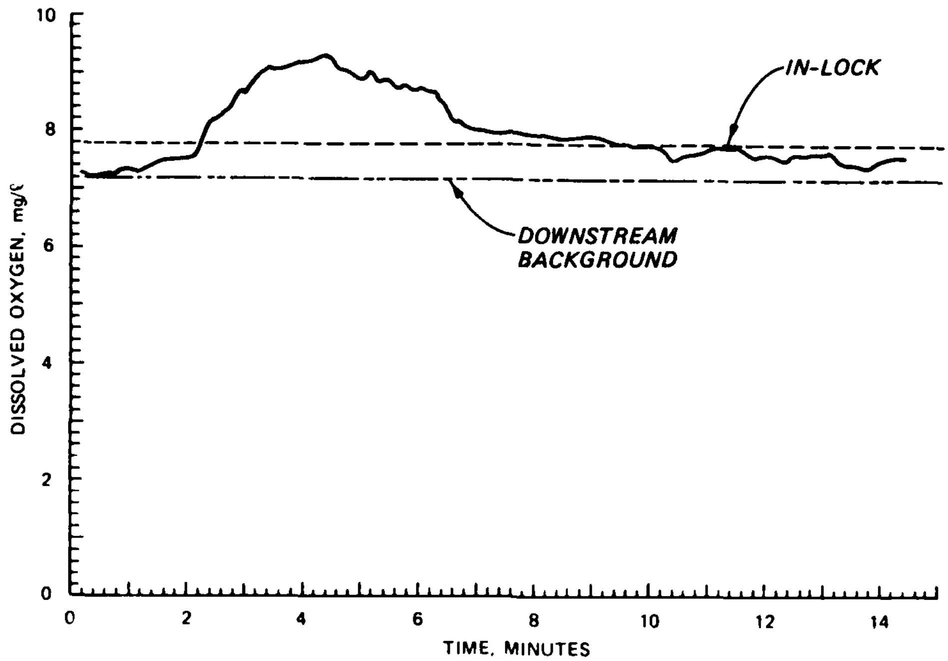


a. Test 1

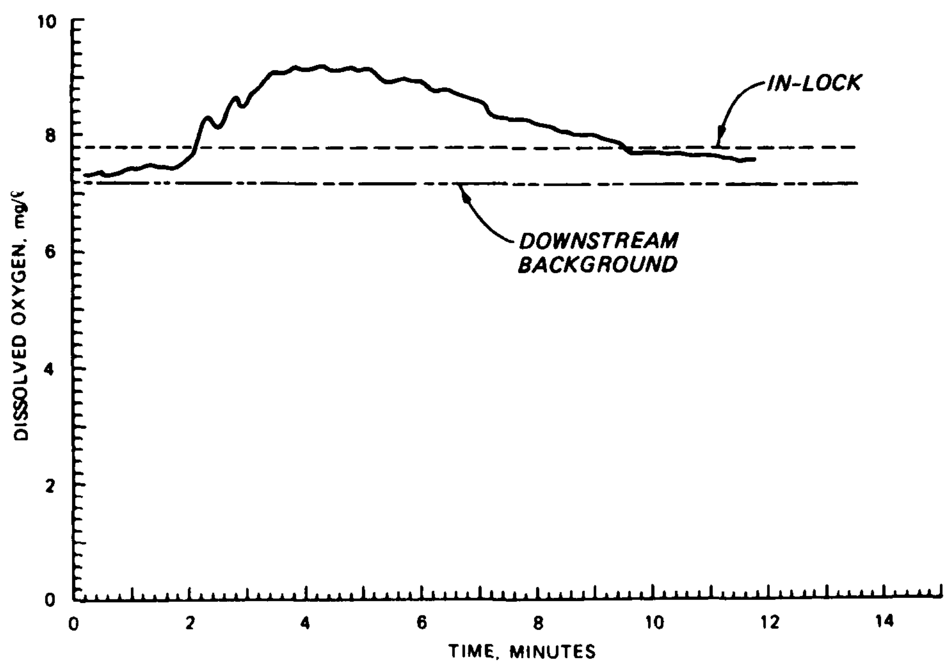


b. Test 2

Figure 16. Pickwick Lock emptying oxygraphs, 1981



a. Test 1



b. Test 2

Figure 17. Pickwick Lock emptying oxygraphs, 1982

additional testing to determine the DN increase that occurred during emptying. These locks were selected because of the oxygen supersaturation that occurred during release operations. Total dissolved gas pressure was monitored during emptying. Based on water temperature, barometric pressure, and average observed peak TDGP and DO, the nitrogen concentrations and saturation levels presented in Table 1 were determined.

25. These data suggest that where air entrainment is significant, gas supersaturation may occur. The highest total dissolved gas (TDG) saturation observed was 119 percent at Pickwick Lock. This, however, corresponds to peak dissolved gas uptake. The average release TDG saturation (based upon a flow-weighted average) would be significantly less.

Table 1

Nitrogen and Oxygen Concentrations and Saturations

Project	Peak Total Gas Saturation percent	DO Peak mg/ℓ	DO Percent Saturation	DN Peak mg/ℓ	DN Percent Saturation
Guntersville (1981)	*	11.3	139	*	*
Guntersville (1982)	110	8.8	107	14.8	110
Demopolis (1981)	*	8.0	106	*	*
Demopolis (1982)	108	8.4	112	13.6	110
Pickwick (1981)	*	9.2	115	*	*
Pickwick (1982)	119	9.3	115	15.8	119

* Data not taken.

Discussion

26. Since filling was relatively smooth with little turbulence in the lock chambers, there was usually insignificant DO uptake during the lock-filling operation. At the projects where air was aspirated through

controlled vents downstream of the filling valves, the DO increased above initial in-lock DO during the early stages of filling (Holt and Wilson Locks). However, about halfway through filling, aspiration ceased and the large volume of inflow into the lock significantly diluted the DO uptake. The net change in DO concentration was negligible.

27. Several locks displayed significant reaeration characteristics. At Demopolis, Holt, Guntersville, Wheeler, Wilson, and Pickwick Locks, the in-lock and downstream background DO concentrations were below the peak DO concentrations in the respective releases. Enhanced release concentrations were produced by air entrainment into the release and the turbulence generated during lock emptying. The effect of entrained air was particularly clear from the Demopolis, Guntersville, and Pickwick Lock data. The in-lock DO and downstream background DO concentrations were much less than the peak DO on the oxygraph. The hydrostatic pressure to which the entrained air and water are subjected during transit from the emptying valve to the outlet resulted in supersaturated DO concentrations.

28. A process that occurred simultaneously with oxygen uptake was an increase in dissolved nitrogen. The highest DN supersaturation measured was 119 percent at Pickwick Lock. This degree of supersaturation persisted for a relatively short time and, in general, significant adverse impacts would not be expected because this corresponded to a peak concentration. The flow-weighted average concentration would be much less. Designers and operators of navigation locks and other hydraulic structures, however, should be cognizant of this potential problem.

29. Bankhead, Walter F. George, Aliceville, and Gainesville Locks demonstrated very little reaeration. In these cases, the peak release DO did not surpass the in-lock DO level, indicating that very little DO uptake occurred during emptying. The release from the lock mixed with downstream water, causing the DO to initially rise from the background level to the in-lock level, then fall. Improved downstream DO concentrations were due predominantly to release of water with a higher quality than the downstream background.

30. The impact of one or two lock operations upon the downstream

DO concentration was to cause the DO concentration to initially increase from some downstream background level to a maximum, then gradually fall, asymptotically approaching the initial downstream background concentration. This scenario was generally true regardless of the hydraulic conditions at the lock. Only the magnitude of the improvement (peak increase above downstream background DO) was dependent on lock discharge hydraulics. Although one or two lock operations did not significantly affect downstream DO concentrations, these results indicate that an increased frequency of lock releases would have resulted in a gradual increase in the downstream DO concentration to the flow-weighted average concentration of the lock release.

31. Many of the navigation projects that were evaluated were accompanied by a hydropower installation. In most cases, flow through the hydropower project was such that little reaeration occurred. Since the intakes for the powerhouse were typically located deep in the upstream pool, low DO releases resulted. The lock intakes were relatively high in the pool; thus, the effect of lock operation was to withdraw and release higher quality water and cause reaeration that maintained or improved downstream DO concentration.

Conclusions

32. It is concluded from this study that releases from a navigation lock generally improved or at least maintained existing DO concentrations downstream. Particularly in cases where a powerhouse was operated, reaerated releases from a lock improved the downstream DO. In most of these cases, the in-lock DO was as high or higher than downstream DO concentration. If the in-lock DO were below saturation, reaeration during emptying enhanced the release concentration. In several cases, significant oxygen uptake occurred during lock emptying. Air entrainment at the emptying valve and downstream turbulence appeared to be the major causes of this oxygen uptake into the release flow. In the occurrence of large air entrainment, some short-term supersaturation of

nitrogen occurred but did not appear immediately detrimental to aquatic life.

33. At some navigation locks, simple modification to the emptying valve air vents may be an alternative to enhance the release DO. In some cases, a change in valve operation could result in significant air aspiration. In others, simple structural modification, such as a deflector in the release conduit, may be required to cause aspiration. Research is needed to define and develop some of these structural and operational alternatives on a general and site-specific basis.

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